7 RISK MANAGEMENT OPTIONS FOR CAFO WASTE

Now that the risks associated with the large amounts of animal manure present at CAFOs have been described, this document will now discuss what may be done to mitigate CAFO manure pollution. This section will be divided by strategies that are well known, those requiring some additional research, and those strategies that are new and innovative and require significant additional research to fully implement. Within each section we will describe how the strategies discussed will mitigate each of the stressors identified in this document: nutrients, pathogens, EDCs and antibiotics.

Two well known risk management strategies, discussed in detail below, are land application and composting. Land application is the main means by which animal manure from CAFOs is disposed. This often results in excessive application that results in release of manure stressors into the environment. This makes land application part of the problem. It may also be part of the solution if done properly.

7.1 Land Application

This section summarizes the benefits and risks associated with land application of CAFO waste. Application of animal waste to land presents a complex set of topics for consideration. Animal manure has been applied to soil primarily as a disposal operation since the Roman Empire. Similarly, use of animal manure to enhance soil fertility has been known for about as long, but the underlying reasons were only illuminated within the last 150 years. Manure as a fertility agent has several benefits for agricultural production. The advantages come from the value of animal manure as a fertilizer and soil conditioner (Kellogg et al., 2000; USDA/NRCS 1996,1998; Weidner et al., 1969). The nitrogen and phosphorus content of manure has a real value, when substituted for inorganic chemical fertilizer (Bitzer and Sims, 1988;Edwards and Daniel, 1992). The soil conditioning aspect is important. As soil organic matter increases, soil workability improves leading to lower power requirement for equipment. Water holding and infiltration improve leading to greater drought resistance. Nitrogen, phosphorus, and potassium are recycled into the soil with applied manure, thus maintaining fertility. Major portions of N and P in manure are in organically bound components, which function as slow release nutrient sources. The organic matter component of manure maintains or enhances the soil organic matter fraction. The benefits of manure application to soil are well recognized. For most purposes the smaller farm operations may gain the benefits with relatively minor problems.

The liability comes from the need to have adequate land for disposal/treatment, the cost of application including capital costs, labor and transportation costs and the potential environmental liability, should a nearby water body be contaminated by wastes. The task of balancing the advantages and disadvantages lies in successfully measuring the nutrient content of manure and calculating application rates (Iowa State Univ. 1995; Maguire et al., 2000; USDA 1979; USDA/NRCS 1996,1998; Weidner et al., 1969). Allowances must be made for the available N from manure, losses to atmosphere as NH_3, and potential variation in application. Managing application by N content usually results in over-application of P. Managing by P content under supplies nitrogen leading to a need to add inorganic N. Since there are differences in application equipment for manure or inorganic fertilizer, that portion of costs increases.

Every segment of animal agriculture production has examples of waste load exceeding the absorption capacity of the local environment. As discussed in the beginning of this document, the problem derives from concentration of production facilities into relatively small land areas, with little space available for waste disposal. Some facilities market the waste as fertilizer material, but the transport distance becomes the limiting economic factor (Bosch and Napit 1992). The key question for consideration in this risk management evaluation is how to properly use land application to reduce the risk to water quality from CAFO manure while still realizing its many tangible benefits. Answering this question requires an examination of how manure is currently used and how it may be used more efficiently.

Numerous documents exist providing guidance to the farm operators on every aspect of application of manure to soil. There are documents produced by the USDA, States, and universities that provide examples of how to calculate the fertilizer value of different wastes. The publications provide models of how to substitute manure for inorganic fertilizer to meet yield goals. The key factor is that every facility presents a unique situation with regard to soil type, waste type, soil conditions, erosion potential, and climate. There are no universal solutions for using CAFO wastes as a fertilizer source. Some general principles do apply however. Application rates should be based on the more restrictive crop phosphorus requirements. Waste application should be timed to provide maximum benefit for crops. Manure should not be spread on land in winter where the ground is frozen. Wherever possible, incorporation should be done within 24 hours of application. Soil management to minimize erosion will help mitigate any runoff problems associated with manure. This section is intended to provide an overview of the practices used in land application, some of the problems attendant with land application, and some management practices to minimize problems. The literature citations provided represent a small fraction of available material concerning the subject.

7.2 Practices Used in Land Application

7.2.1 Application Systems

Transport of manure from the site of production or storage to the fields where it is applied may take many forms. Some are simple load and spread systems. Some are more complex with mixing, shredding, pumping and distribution machinery involved. The type of system used varies with the characteristics of the waste being handled. Different animal production facilities have elected different waste handling modes that are most commonly based in ease of operation and cost. Liquid manure application may take several forms (Doughherty et al., 1998). Tractor drawn or truck mounted tank systems may either broadcast or directly inject liquids (Figure 7.1). Tractor pulled broadcast or injection applicators can be supplied by drag hoses or temporary holding tanks. This option reduces potential soil compaction.

Irrigation application may be flood type, gated channels, or various kinds of sprinkler systems. Sprinkler systems may be manually moved, fed from a central pumping station; fixed installation; or center pivot type with central pumping. Use of irrigation type systems may be limited to larger facilities in some cases simply because irrigation systems need a minimum flow volume to function properly. A major drawback to spray irrigation systems for the application of liquid manure is the loss of NH_4-N to the atmosphere as NH_3. The value of the N is lost and the odor potential is high for sprayer systems. Irrigation may serve two functions, one to supply nutrients and the other to supply water to meet crop needs. In some ways, liquid systems may be more limited than others. Installed irrigation equipment is not easily moved; therefore, the same land is repeatedly treated with manure. Other nearby land potentially suitable for receiving manure may be passed over.

The major animal production sectors use different waste handling systems. Factors involved in the elected choices vary from locale to locale. Available data are limited and apply to large production facilities. Some examples of manure distribution systems are listed in Figure 7.2.

Photo courtesy of USDA NRCS.

Figure 7.1. Tractor drawn liquid manure application after corn harvest.

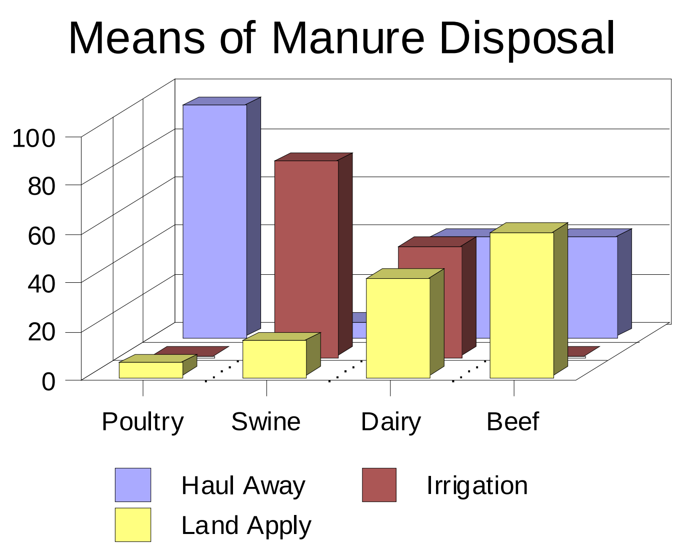

Figure 7.2. Means of manure disposal by animal sector.

7.2.2 Potential Problems Associated with Manure Applications

Although the problems associated with nutrients, pathogens, EDCs, and antibiotics in manure are common to all species of livestock, some additional problems are posed by the way in which the manure is disposed. This is related to the moisture content of the manure, which is related to the species of livestock in question. As shown in Figure 7.2, almost all of the manure generated by poultry facilities is sent off-site for disposal. Environmental pollution resulting from runoff is probably not a big problem at these facilities as a result of this practice. Nevertheless, myriad problems could result from the off-site transport of poultry waste because the nutrient and pathogen load of the waste will be out of the direct control of the originating facility.

Over-enrichment with N and P may occur when liquid waste is sprayed on land as is done at swine CAFOs. Air pollution may result from volatilization of NH_3 when downwind transport occurs as a result of spray irrigation using liquid waste and wastewater. Runoff of oxygen demanding substances, nutrients, and pathogenic organisms to water bodies may accelerate eutrophication of receiving water and spread pathogenic microorganisms throughout the watershed. (Baxter-Potter and Gilliland, 1988; Culley and Phillips, 1982; Doran and Linn, 1979; Doran et al., 1981; Edwards and Daniel, 1992; Gagliardi and Kerns, 2000, Giddens and Barnett, 1980; Gilley and Eghball, 1998; Jawson et al., 1982; Larsen-Royce et al., 1994; Pell 1997; Smith et al., 1985; Wolf et al., 1988).

Transport of nutrients and microorganisms to groundwater may also occur from both the application of liquid waste and the spreading of solid manure on land. Another avenue for nutrient losses exists in the leaching of soluble nutrients either to groundwater or drainage tile (Entry and Farmer, 2001; Evans et al., 1984; Gangbazo et al., 1995; Simpson 1990). N applied in manure as NH_4^+ will exchange on to soil cation exchange sites. This form of N does not readily move, but may be nitrified to NO_2^- and NO_3^- (Eghball 2000) that are freely mobile in soil water. Subsequently, denitrification may reduce the NO_3/ NO_2 to N_2O or N_2 (Rochette et al., 2000; Stevens et al., 2001)

Even the subsurface injection of solid manure may contaminate water sources as the result of channel flow through the vadose zone. The channels may take the form of worm burrows, root channels, or animal burrows. P usually rapidly converts to insoluble forms, but with high application rates and rainfall, P will move as soluble P. Water-soluble organic N and P may also move into groundwater or drainage tile. Movement of NO_3^- into groundwater may increase NO_3^- levels above the federal standards of 10 mg/L. Too much NO_3^- in water presents a risk to very young children by causing methemoglobinemia (already been said). Loss of N and P to drainage tile primarily represents loss of the fertilizer value of the applied manure. It also increases the potential for eutrophication of receiving waters.

The bacterial load of animal waste either applied to the soil surface or injected below ground may enter the channels existing in the soil and migrate into drain tile. If water flow is relatively large, the water may transport organisms including pathogenic organisms to receiving streams, lakes, or ponds. This pathway is easily overlooked as it is assumed that water entering drain tile has been filtered through the overlying soil. Studies of the movement of bacteria through the soil profile are recent. Entry and Farmer, 2001 examined coliform and nutrient movement in a sand aquifer below fields irrigated with river water. Smith et al., (1985) also showed that *E. coli* could move through soil most easily in undisturbed soil columns. Tilled soil was more effective in retarding the movement of the organisms. Gagliardi and Kerns, (2000) reported that *E. coli* O157:H7 could move through agricultural soils under different management practices. Patni et al., (1984) studied the bacterial quality of water in tile drains under manured and fertilized cropland. Their results showed that bacteria could move easily through the soil profile. Shipitalo and Gibbs, (2000) showed that injected manure could move to tile drains within minutes of application through worm burrows. The width of the transmission zone was about one meter at the soil surface.

Because movement of microorganisms through soil profiles has been observed, it is also likely that EDCs and antibiotics may move with the water flowing through the same channels that allow passage of the microorganisms.

7.2.3 Soil Management Practices to Reduce Problems

Control of potential pollution from land-applied manure requires attention to good soil management practices (Cook et al., 1996; Dillaha et al., 1986; Young et al., 1980). Soil management to reduce erosion losses will reduce potential manure runoff losses of oxygen demanding compounds, N, and P. The most important factors contributing to or limiting erosion include: degree of slope, susceptibility of soil to detachment, crop cover, rainfall, and presence of erosion control practices (Cook et al., 1996; Dillaha et al., 1986; Liu et al., 2000).

7.2.4 Runoff Control from Land Application Fields

Runoff from the immediate CAFO operation is best controlled at the source as described above. However, runoff control in a land application of animal waste is not as easily managed. The large areal coverage typical in land application makes management of the waste more difficult. In most applications, the primary stressor of concern will be the nutrients. Nitrogen as found in animal waste is soluble and will be transported via the water (Eghball 2000). Phosphorus, , however, is particle-bound and will be transported through erosion and sediment transport. Effective controls for phosphorus will require measures to prevent the detachment, transport, and deposition of soil particles to a receiving water. Typical erosion control strategies may be used to minimize the SSAS and associated stressors delivered to a water body.

In a land application of waste, the most effective management for SSAS is to retain the soil and solids applied to the field. There are three primary points to reduce the SSAS from land application: 1) reduce soil detachment, 2) reduce transport within the field, and 3) trap sediment after the field.

7.2.4.1 Reducing Soil Detachment

To effectively reduce the soil particle detachment, the energy from a falling rain droplet must be adequately dissipated. Crop cover and crop residue may dissipate energy to varying degrees depending on the extent and type of coverage (Woo et al., 1997). Accepted conservation practices such as conservation tillage, cover crops, contour farming, buffer strips, riparian buffer, and effective pasture management may significantly reduce the soil detachment due to direct rainfall.

Conservation tillage reduces vulnerable soil exposure by maintaining a cover crop and/or crop residue on the soil surface. Examples of conservation tillage include preparation of seedbed bands only for rowcrops, chisel plowing or disking to incorporate plant residues vertically into the soil surface rather than turning under as with a traditional plow. Approximately 45% of crop production in the US occurs with conservation tillage. Use of reduced tillage is not conducive to incorporation of applied manure. Similarly, tillage of pastureland or hay production field would not be done. Chisel plow type injection could be used on these lands to a limited extent. Leaving crop residues on the soil and planting cover crops will reduce raindrop impact on the soil, thus reducing the detachment of soil particles that could erode.

On sloping land, contour strip fields may be used to control water flow (Liu et al., 2000). Alternate strips of different crops are planted perpendicular to the slope to reduce water velocity and retain sediments. Crop rotation may reduce runoff by including a hay type crop between row crop years. The potential soil erosion from hay is much less than row crops. Provision of buffer zones, terraces, filter strips, and windbreaks may all reduce soil erosion by slowing the speed of water and wind across the soil surface. These measures may also collect particulates in motion, preventing them from reaching larger streams.

Proper pasture management may reduce pollutant movement. The best time to apply manure to hay acreage is subsequent to removal of the last crop. Then there would be a substantial time for the manure to be absorbed with little risk of bacterial contamination of harvestable crops. Similarly, manure may be applied to wheat and oat fields after harvest of the grain and straw. The manure could be absorbed prior to seeding of the next crop or as the soil is prepared for the next crop.

Atmospheric losses of N may be curtailed by incorporating manure either by direct injection or by tilling within 24 hours after application. For some crops, the incorporation of manure may be combined with preparation for seeding. One factor in reducing NH_3 volatilization from soil is that most agricultural soils have pHs in the range of 6 to 7.5. Ammonia will tend to remain in soil at that pH.

7.2.4.2 Reducing SSAS Transport within a Field

To effectively reduce the transport of SSAS within a field, techniques to minimize runoff, increase infiltration, and trap sediments are used. Similar conservation techniques described for reducing soil detachment may also reduce the within-field transport. The use of cover crops and crop residue will effectively reduce the runoff velocity and trap sediments. The type and extent of cover crop or crop residue will control its effectiveness. Contour farming, strip cropping, and conservation tillage may all effectively reduce within-field transport. Diversion of runoff from up-slope areas may also reduce the runoff on the targeted field.

Cover crops also immobilize nitrogen and phosphorus effectively converting the elements into slower release forms. Along streams, other management practices may be implemented to reduce the potential for eroded material to enter the water. Riparian buffers of trees, grass, and shrubs may reduce transport of material to the stream. They are discussed in more detail in the next section.

Many agricultural areas of the United States require drainage of the soil by tile to be fully productive. In those areas, limiting of the amount of applied nutrients would be the best way to control the movement of nutrients to drainage paths. Areas of the US that have significant karst landforms are also susceptible to significant losses of N and P in drainage water (Stoddard et al., 1998). Some of the soils are quite shallow and may rapidly allow movement of water and dissolved nutrients to streams and lakes

7.2.4.3 Trapping Sediment after the Field

The final point of control is trapping sediment after the field. Though this should effectively reduce the sediment load to a water body, this technique is treating the symptom and not addressing the problem. Efforts should be made to reduce the generation of SSAS, not simply trap or intercept them. Trapping strategies include grassed buffer strips, diversions, detention basins/ponds, riparian buffers, terraces, and wetlands. These solutions generally approach a more engineered solution versus the first two phases of erosion prevention (preventing soil detachment and within-field transport). Efficiencies vary based on design and operation of the control structure (Butler and Karunaratne, 1995). In addition, many of the strategies have multiple functions in the prevention of erosion as shown as in Table 7.1. These strategies are used alone and in combination to address the erosion problem.

Table 7.1 Functions of soil conservation practices (Adapted from USEPA, 2001a).

Conservation Practice	Soil Detachment	Within Field Transport	Sediment Retention
Conservation tillage	X	X	
Contour or Cross-slope Tilling		X	
Contour strip cropping/Contour Buffer strips	X	X	X
Cover crops	X	X	
Crop rotation	X	X	
Diversions		X	X
Field borders		X	
Filter strips		X	X
Grassed waterways	X	X	X
Ponds		X	X
Riparian buffers		X	X
Sediment basins		X	X
Terraces		X	X
Wetlands			X

Depending on topography, waterways on a farm could lead to sediment traps or constructed wetlands that would intercept much of the sediment and nutrient load that leaves the fields. Periodic cleaning of these structures would be necessary to retain capacity.

Riparian zones are areas usually associated with the banks of river or stream corridors and are areas where subsurface flow (groundwater runoff or base flow) reaches either the ground surface or near surface before contributing to stream flow, causing elevated water tables and high soil moisture condition that typically support a variety of vegetation. Riparian zones impart a variety of beneficial influences upon streams such as reducing sediment and nutrient loads, mitigating the severity of flooding, and increasing soil permeability and soil organic content.

In addition to the physical benefits just mentioned, riparian zones may also exert a chemical influence on groundwater runoff, most notably conditions that favor nitrate reduction. The ability to support nitrate reduction is closely tied to the geology and hydrology of a watershed, and the extent of the riparian zone.

If the soils in a riparian zone are saturated, and anaerobic or anoxic conditions exist, nitrate reduction is possible. In addition to the favorable conditions noted, not only must the flow path of groundwater intersect or flow through the riparian zone before discharging to the stream, but also the area where groundwater recharge occurred must be in an area where elevated nitrate levels exist in the soils. In other words, recharge to the groundwater system may occur over a large portion of a watershed or field, but not all of this recharged water will follow a flow path through a riparian zone. Some of the water may move into deep groundwater flow regimes, well below the influence of the riparian zone and into another groundwater system. Some groundwater may appear as spring flow, also bypassing the riparian zone. Still other groundwater may follow a flow path that travels below the riparian zone (rather that laterally through the riparian zone), then vertically upward into the stream minimizing any contact time within the riparian zone.

Seasonal variations also affect the influence of the riparian zone. During wet seasons, the water table may be elevated and intersect the stream creating the favorable conditions for nitrate reduction. During drier periods, the water table may drop, and groundwater runoff that previously would have followed a flow path through the riparian zone will now flow beneath the zone without any reducing effects.

Finally, even if the flow path that groundwater runoff follows is lateral through the riparian zone, only runoff that originates in an area that has elevated nitrate will experience possible nitrate reduction. This becomes important when areas are chosen for the application of animal waste. If the goal is to incorporate the benefits of a riparian zone into the management of animal waste, the waste must be applied in areas where the runoff generated, both surface and subsurface runoff depending on the benefit desired, will flow through the riparian zone.

The two primary nutrients in animal waste behave almost opposite to runoff or precipitation. Phosphorus (P) is primarily transported as particulate P in runoff, although there is an important component of soluble P, whereas nitrate is highly soluble and is more readily leached into the groundwater. As noted previously, this may be a factor in deciding where to place animal waste within a field or watershed. Precipitation events that are insufficient to produce runoff that would carry P to a receiving water body are typically insufficient to mobilize sediments. Finally, even if the flow path that groundwater runoff follows is lateral through the riparian zone, only runoff that originates in an area that has elevated nitrate will experience possible nitrate reduction.

7.3 Composting of CAFO wastes

Composting of CAFO and AFO wastes benefits the environment because nutrients contained in manure, livestock carcasses, and other materials are converted to stable forms in the compost. Therefore, these nutrients are less likely to leach into groundwater or to be carried off with surface runoff. In addition, the total mass of material is reduced in the composting process. Compost may be easily stored until conditions are favorable for land application and therefore possibly minimizing the impact to environmentally sensitive areas. Another advantage of composting is that due to high self- heating (55-65°C), the process is generally self-pasteurizing for most pathogens, provided that the minimum time and temperature conditions have been met. The main concerns of composting these types of wastes are pathogen control, nitrogen volatilization and leaching, excess available phosphorus, and economic viability of composting depending on type of system required.

7.3.1 What is Composting?

Composting is a useful tool in waste management because it may rapidly transform putrescible material to a stabilized product that may be stored, transported, and used as a soil conditioner/fertilizer (May nard 1993). In composting, a solid-phase organic material such as manure mixed with a bulking agent (corn cobs, corn stover, straw, wood chips) serves several functions. The solid organic phase is a physical support for microorganisms, maintains pore space for gas exchange, is a source of organic and inorganic nutrients, contains diverse indigenous microbes, and provides thermal insulation. Water may be added to maintain the proper moisture content of the compost. The major form of microbial metabolism is aerobic respiration. The heat generated during the exothermic reactions of metabolism becomes trapped within the matrix causing self-heating, which is characteristic of the composting process. The critical elements of successful composting are a proper carbon to nitrogen ratio (15-40 to 1), adequate oxygen supply, temperature control, maintenance of moisture, and provision of an adequate time period to reduce pathogens to appropriate levels. All composting systems may be described by their means of regulating the initial oxygen supply and maximum temperature (Finstein and Hogan 1993). For a more in-depth review of all the possible composting configurations based on oxygen supply and maximum temperature, along with a brief discussion of whether that type of system is currently practiced and, if practiced, how the technology is faring, see Finstein and Hogan (1993). For a review of the composting process parameters for animal wastes or other organic wastes, see the following references: Agriculture Waste Management field handbook by the U.S. Dept. of Agriculture and On-farm composting handbook by NRAES-54 (Dougherty 1999, Rynk 1992.

7.3.2 Composting systems

In order to avoid a long and lengthy list of composting systems in practice and vendor specification to define composting systems, the basic outlook of man over mechanical intervention required to compost will be discussed in order to save space. The current practices and system types utilized by poultry, cattle/dairy, and swine will be discussed later. There are basically two types of composting systems, interventionary and non-interventionary (Stentiford 1993).

7.3.2.1 Interventionary Systems

Interventionary systems are systems that require mixing as an aeration process, and these systems may also have some form of supplementary aeration. These systems may take many forms such as windrows, agitated bays, stirred vessels, and multi towers. The main advantage with interventionary systems is that mixing of the waste prior to composting is not as critical as it is in non-interventionary systems. These systems are better suited for the composting of putrescible wastes because they allow the composter to adjust parameters, such as moisture and amount of bulking agent, while the composting process is ongoing.

7.3.2.2 Non-Interventionary Systems

In non-interventionary systems, the initial conditions of the feed material are critical for successful operation. Non-interventionary systems consist primarily of aerated static piles and silo systems. The silo system was not proven to be an effective method of composting due to aeration and moisture control problems inherent with the system design. The aerated static pile has proven effective with composting many wastes, but it must be emphasized that this system is not dynamic. The system must be carefully constructed in order to provide uniform heating and moisture throughout the process since no other intervention will occur. This means that the risks of composting failure to achieve the desired results of pathogen destruction and nutrient stabilization are higher with this type of system (Lufkin 1996, Mathur 1990, Sartaj 1997).

7.3.3 Comparison of Interventionary and Non-interventionary Systems

Each type of system has its merits and associated cost. The interventionary systems offer the operator improved control, shorter processing time, and reduced land use, but with these advantages comes increased price of setup and operation. The non-interventionary systems offer the operator low setup and operational costs but requires increased land usage, increase in the time required for stabilization, and little or no control of the process (Stentiford 1993, Sartaj 1997, Vuorinen 1999-1997). Therefore, the type of process utilized to compost the CAFO and AFO waste streams must take into consideration the time frame, costs, distance to population centers, and the systems' ability to meet final regulatory requirements.

7.3.4 Composting in the Beef and Dairy Industries

7.3.4.1 Beef

Since manure from the beef cattle occupying range and pastureland is dispersed by the animals, composting in the beef cattle industry is limited to manure generated at feedlots (Kashmanian 1996). Composting is generally performed by the feedlot owners or sub-contractor at the facility. The windrow method of composting is the most commonly practiced method (Lufkin 1996, Rynk 1992, Mathur 1990).

The manure may be composted alone or by mixing the manure with locally available carbonaceous feedstocks, such as straw, newspaper, or yard trimmings. The additional carbon sources help in raising the C/N ratio and reduce the loss of nitrogen as a result of ammonia volatilization (Hong 1997, Larney 1999). The handling of the material is usually performed by either a front-end loader or a windrow turning machine. The final compost is either sold commercially for landscape and gardening or sold in bulk for crop production.

7.3.4.2 Dairy

The sources of manure readily compostable from the dairy industry are the bedding materials used in barns and partially dried manure from the open lots. Another source of material found in the dairy industry is manure solids separated from liquid collection systems. Dairy wastes from bedding and open lots may be composted as is, but the composting process benefits from the addition of high carbon substrates in order to minimize nitrogen loss due to volatilization (Hong 1983, Hong 1997). As with beef cattle, the method of composting applied by dairy farmers is windrows. The windrows are either static or forced aeration with turning methods as described above. The forced aeration systems are generally used by larger facilities that do not have the land or storage ability to deal with nutrient management issues due to the high manure load (Joshua 1998, Fernandes 1997). Some composting at dairies is performed by outside organizations and sold to commercial outlets. The dairy industry has recently adopted some practices that do not favor composting as a waste management practice. These practices are the use of bedding mats or sand in free stall areas, and many larger farms are switching over to liquid manure handling systems. The liquid systems increase the cost associated with dewatering solids and increase the amount of carbonaceous materials needed to compost. Another disadvantage of these practices is the increased moisture present at the initiation of composting requires that the compost must be turned more frequently until the moisture level becomes more favorable (40-50%). If the moisture level remains too high then the composting system has a tendency to become anaerobic which leads to the production of foul odors (Kashmanian 1996).

7.3.4.3 Composting Swine Waste

Due to the wet nature of swine waste and the current practices of water waste collection the swine industry is the least suited for composting. A small number of operations raise swine in a deep bedding method in which the waste is absorbed by straw or sawdust. After the swine are raised, this bedding material may then be composted by any number of means (Hong 1998, Lau 1993, Peterson 1998, Tiquia1997-98). Most other systems use a liquid method for waste collection, and, therefore, the solids need to be removed from the waste stream in order to compost. The separation may be performed by several methods (centrifugation, screening, and presses) but all methods add to the cost and handling of the waste (Liao 1993, Kashmanian 1996). Due to the wet nature and the high nitrogen content of the swine manure, a readily available source of high carbon bulking materials would be necessary in order to compost this material. One area of composting that is gaining attraction in the swine industry is the composting of mortalities. This is a relatively inexpensive way to deal with mortalities since the cost of rendering and number of rendering facilities across the country is declining. Only a limited number of states allow this form of composting and the accepted methods vary slightly from state to state. The pathogens associated with the swine industry *(Salmonella typhimurium, Streptococcus suis, Bordetella bronchiseptica, Listeria monocytogenes, Actinobacillus suis, and Actinobacillus pleuropneumoniae*) have been shown to be sufficiently killed by the high temperatures of the composting process (Morrow 1995). The composting of mortalities is limited to normal fatalities and is not an acceptable method for the disposal of a large number of animals due to a system failure.

7.3.4.4 Composting Poultry Waste

Poultry manure is readily compostable due to the method of raising animals in confined areas and the dry nature of the material. This manure generally requires the addition of carbonaceous materials due to its high nitrogen content (Figures 7.3-7.4). Water must also be added to poultry manure and/or litter to ensure proper initial composting conditions (Flynn 1996, Hansen 1990, Spencer 1997). One of the advantages of composting to the poultry industry is the relative small land size of poultry operations, and, therefore, they do not have adequate land for application of raw manure. Composting allows the poultry producer to stabilize a waste product on a small area while creating a potential value added product. Commercial outlets for the finished material are one solution that several producers have utilized (Lufkin 1996). Most poultry operations practice composting of mortalities since it is an environmentally acceptable practice and other forms of disposal are facing increased restriction and increased cost (Kashmanian 1996). National standards for the practice of poultry mortality composting are published by the U.S. Dept. of Agriculture's National Resource Conservation Service. Many state and national guidelines are available on the web for the composting of poultry mortalities.

Photo courtesy of USDA NRCS.

Figure 7.3. Mixed compost from turkey waste.

Photo courtesy of USDA NRCS.

Figure 7.4. Turkey waste compost with wood chips and feathers.

7.3.5 Composting Concerns and Problems

The type of manure handling practice has a large impact on whether a particular farm is going to compost or not. Composting is generally practiced on farms that handle their manure in a solid or near-solid consistency. Composting is rare on farms that utilize liquid techniques for manure handling, such as swine and dairy operations. There are some exceptions because of solids separations techniques, but these add cost to the final operation and may therefore be impractical in some operations (Liao 1993). In order to address the high moisture and high nitrogen content of the waste, a locally available source of carbonaceous materials must also be readily available (Dougherty 1999, Rynk 1992, Hong 1983). The volatilization of NH_3 is a major concern in the composting of manures because it lowers the fertilizer value of the finished compost and produces environmental air quality issues.

7.3.5.1 Nutrients.

There has been some study of the effect of C/N ratio on the volatilization of NH_3 from poultry and sewage sludge composting operations (Hansen 1990, Hong 1997, Kirchmann 1989, Larney 1999, Lopez-Real 1996). In order to minimize the loss of NH_3, a higher C/N ratio is more favorable. The use of either a soil or carbon source cover has also been shown to minimize ammonia volatilization (Hansen 1990). Another factor that seemed to help in the retention of nitrogen during composting is the recycling of compost back into the initial feed material. This practice, though, is generally only used to inoculate the composting system, since it reduces the overall mass loss and requires additional handling of the same material (Larney 1999, Hansen 1990). No information was found on the nitrogen content of potential leachate from composting materials.

7.3.5.2 Pathogens

Pathogens associated with these waste streams fall into two categories, primary and secondary pathogens. The primary pathogens consist of bacteria, viruses, protozoa, and helminths. When the composting process is run correctly, it is very efficient at destroying primary pathogens, and exposure-related infectious disease from primary pathogens among compost workers has not been documented. (Epstein 1993, Bertoldi 1988). To be effective at pathogen removal the composting process must attain a temperature greater than 55°C for more than three consecutive days (Choi 1999, Rynk 1992, Bertoldi 1988). Although there are no federal regulations for the composting of manures, the US EPA addresses pathogen reduction guidelines, which may be applied to manure, for the composting of biosolids in the September 1989 report entitled "Environmental Regulations and Technology: Control of Pathogens in Municipal Wastewater Sludge," EPA/625/10-89/006, p21, To be considered a PFRP, the composting operation must meet certain operating conditions. These regulatory conditions are specific to the method of composting practice. For windrow composting, the sludge must attain a temperature of 55°C (131°F) or greater for at least 15 days during the composting period. In addition, during the high-temperature period, the windrow must be turned at least five times. If the static aerated pile or the within-vessel method is used, the sludge must be maintained at operating temperatures of 55°C (131°F) or greater for 3 days. This temperature requirement is effective at removing most, if not all pathogens. The removal of *Salmonella* and other pathogens during the compost process has been demonstrated for a variety of animal wastes. Lawson (1999) showed the removal of pathogens during the composting of poultry carcasses and litter. Lung et al., 2001, demonstrated the removal of *Salmonella* and *E. coli* O157:H7 during the composting of cow manure. This study showed no removal of either pathogen in reactors held at room temperature. Tiquia et al., (1998) in a study of pig litter composting *Salmonella* was reduced from 1700 per gram to below detection limit and a greatly reduced (not specified) population of fecal coliforms and streptococci. The fecal coliforms and streptococcal numbers were below the amount found in commercially available potting mixes. The only primary pathogen of concern is the possible regrowth of *Salmonella* by reinoculation of unfinished compost (Burge 1987, Russ 1981, Tiquia 1998). Other pathogens are not addressed in recent literature. This has been shown to be a possible problem from the composting of biosolids/sewage sludge and therefore could also be a potential problem in the composting of manures (Burge 1987). There has been some study of the suppression and regrowth of *Salmonella* in composts at different ages of material by Sidhu, 2001. In this study, *Salmonella* was inoculated into sterilized and regular composts of various ages. *Salmonella* regrowth was similar in all sterilized composts, with terminal populations of about 100 per gram. The growth of *Salmonella* was suppressed in all non-sterilized composts regardless of the age of the material. The suppression ability of the compost showed a slight decline with time, and, therefore, more study is needed to look at the effect of long term storage and regrowth of pathogens. Good composting practices that avoid cross contamination of raw and finished product alleviates this problem. Storage of compost for 30 days after the active phase of composting has been shown by Gibbs, 1998, to reduce the number of *Giardia* cysts to below detection limits (<10 cysts/gram).

"Secondary pathogens" fungi and other microorganisms produced during the composting process are of concern. The largest health threat seems to come from a secondary pathogen, the heat tolerant fungus *Aspergillus fumigatus*, and several related fungi, which cause "aspergillosis" (also known as "farmer's lung" or "brown lung" disease). This fungus, a well-known product of silage, manure compost, and wastewater sludge compost, grows well on decaying vegetable matter at temperatures above 45°C, and thus survives most of the composting process. Infections in susceptible individuals (including those on immuno-suppressant drugs, antibiotics, adrenal corticosteroids, or with pulmonary disease, asthma, and certain other infections) may be severely debilitating and even fatal. Such infection appears related to high levels of "infective units" in dusts, perhaps reflecting interaction with other materials as irritants, because the organism itself is ubiquitous and not regarded as an off-site or product-related problem (Epstein 1993).

7.3.6 Land Application of Compost

The land application of composted manure has been shown to minimize nitrate leaching into the ground waters (Figure 7.5). The amount of nitrate leached in reported studies was lower from compost-amended plots when compared to conventional fertilizer or direct manure application (Dalzell 1987, Grey 1999). In a study of groundwater by Maynard, 1993, when compost was applied at rates to supply all nitrogen requirements, the compost-amended soils had < 10 mg/kg of nitrate as compared to >14.7 mg/kg for conventional fertilizer application. In a reclamation study of forest soils by Insam, 1997, using various composted and non-composted soil amendments, the nitrate levels below the compost plots were only increased a small amount, whereas the non-compost plots had a highly elevated level of nitrate present in the ground water (<150 mg/L). A three year agricultural study by Diez (1997), which compared compost-amended fields to controls and fields with chemical fertilizers under two different irrigation systems, had mixed results. Under an efficient irrigation system, the compost and control fields had similar low levels of nitrate in the ground water, but under conventional irrigation practices (field flooding in Spain) the compost and chemical fertilizer treated plots had similar nitrate levels. Jakobsen, 1996, performed a pot study looking at the effects of compost-amended soil on mineral availability, soil conditions, and nitrate availability after compost application and after additional fertilizer application. There was some nitrate leaching during winter months from the compost-amended soils after chemical fertilizer was applied but the amount was significantly less than the non-amended control soils. Jakobsen's study also concluded that if compost is applied at a rate to supply the phosphorus needs of the crop, the soil's pH was raised, the cation exchange capacity was maintained, and the soil structure was improved even after a crop had been raised. Another indicator of the stability of nutrients in compost is the agronomic value for estimating availability of nutrients from compost. Values for the availability of nitrogen range from 7 to 25 percent, whereas phosphorus is 100 percent, and potassium is 80 percent for the first year (Grey 1999, Tester 1990, Larney 1999).

7.4 A Strategy Requiring Some Additional Research– Anaerobic Digestion

7.4.1 Technology Description

Anaerobic digestion may be defined as the biodegradation of organic materials in the absence of oxygen. This treatment is particularly appropriate for manure with a high organic (BOD) content. The resulting product is deodorized, has a substantially lower organic load, and has greater nutrient availability (N and P) for crops. The process converts dissolved and particulate matter into a gas, which is primarily composed of methane and carbon dioxide, via a series of interrelated microbial metabolisms (Magbanua, et. al, 2000).

Although different types of anaerobic digester designs exist, only covered lagoons, complete-mix digesters, and plug-flow digesters may be considered commercially available because they are the only ones that have been implemented successfully at ten or more sites (U.S. EPA, 2001).

7.4.1.1 Covered Lagoons

For agricultural waste, anaerobic lagoons are the most common and simplest anaerobic digestion treatment systems (Copeland et. al, 1998; McNeil Technologies, 2000). A covered lagoon digester typically consists of an anaerobic combined storage and treatment lagoon, an anaerobic lagoon cover, an evaporative

Photo courtesy of USDA NRCS.

Figure 7.5. Truck mounted spreader applying compost to a field.

pond for the digester effluent, and a gas treatment and/or energy conversion system. Following treatment, the digester effluent is often transferred to an evaporative pond or to a storage lagoon prior to land application (McNeil Technologies, 2000).

The advantages of covered anaerobic lagoons are the reduction of lagoon odor, exclusion of rainfall from the lagoon, recovery of usable energy, reduction of ammonia volatilization, and reduction of methane emissions. There are also significant labor savings involved in handling manure as a liquid and being able to apply lagoon waters to the land through irrigation (U.S. EPA, 2001c). The limitations of covered anaerobic lagoons include the cost of installing a cover, or the occasional need for cover maintenance such as rip repair and rainfall pump-off. Spills and leaks to surface and ground water may occur if the lagoon capacity is exceeded, or if structural damage occurs to berms, seals, or liners (U.S. EPA, 2001c).

7.4.1.2 Complete Mix Digester

A complete-mix digester is a biological treatment unit that anaerobically decomposes organic waste using controlled temperature, constant volume, and mixing. These digesters may accommodate the widest variety of wastes and are generally used to treat waste with 3 to 10% total solids and adequate volatile solids to produce enough methane to maintain digester temperature (Moser, 2000a,b). The digesters are usually above ground, heated, insulated, round tanks; however, the complete-mix design has also been adapted to function in a heated, mixed, covered earthen basin. Mixing may be accomplished with gas recirculation, mechanical propellers, or liquid circulation. Like covered lagoon systems, digester effluent from complete mix digesters is frequently stored in evaporative ponds. The outflow is recycled onto cropland.

7.4.1.3 Plug-flow Digester

A plug-flow digester is a heated, unmixed, rectangular tank. New waste is pumped into one end of the digester, thereby displacing an equal portion of older material horizontally through the digester and pushing the oldest material out through the opposite end (Moser, 2000a,b). The tank is usually built in the ground and is long and slim and the ratio of the length to the width should be between 3.5:1 and 5:1 (U.S. EPA, 2001c). The outflow may go into an outside storage pond to be held until the manure is recycled onto cropland (Goodrich, 2001).

Overall, some advantages of anaerobic digestion include the opportunity to reduce energy bills, produce a stabilized manure, recover a salable digested solid by-product, reduce odor and fly breeding, and produce a protein-rich feed from the digested slurry (U.S. EPA, 2001). However, the costs of installing an anaerobic digester that collects the biogas may be quite high. Therefore, their economic viability is often dependent on the price at which the excess energy may be sold to a local electrical utility (Prairie Agricultural Machinery Institute, 1997).

7.4.2 Application

Anaerobic digesters are, possibly, the most trouble free, low maintenance systems available for the treatment of animal waste. Farm-based manure facilities are perhaps the most common use of anaerobic digestion technology (Lusk, 1998). Properly designed anaerobic lagoons are used to produce biogas from dilute wastes with less than 2 percent total solids, including flushed dairy manure, dairy parlor wash water, and flushed hog manure. Complete-mix digesters may be used to decompose animal manures with 3 to 10 percent total solids. Plug-flow digesters are used to digest thick wastes (11 to 13 percent solids) from ruminant animals, including dairy and beef animals (U.S. EPA, 2001).

Anaerobic digestion is one of the few manure treatment options that reduce the environmental impact of manure and produce a commodity – energy – that can be used or sold continuously. It is more extensively used outside of the United States where treatment of animal waste has been a concern for a longer time (Moser, 2000a,b).

U.S. livestock operations currently use four types of anaerobic digester technology: slurry, plug-flow, complete-mix, and covered lagoons. As of 1998, 28 digester systems are in operation at commercial swine, dairy, and caged-layer farms in the United States. Table 7.2 provides a numerical status report of farm-based anaerobic digesters in the United States. The data excludes 65-70 digesters that were installed on or were planned for beef farms, and digesters that are primarily university research oriented (Lusk, 1998).

Table 7.2. Status of Farm-Based Digesters in the United States

Type	Slurry	Plug	Mix	Lagoon	Other	Total
Operating	7	8	6	7	0	28
Not operating	0	18	10	1	0	29
Farm closed	0	11	5	1	0	17
Under construction/planning phase	0	2	4	0	4	10
Planned but never built	0	8	1	1	0	10
Total	7	47	26	10	4	94

During the 1990s, 18 systems were installed – more than doubling the number of successful systems installed during prior years. In 23 of the 31 systems, the captured biogas is used to generate electrical power and heat (U.S. EPA, 2001).

Because of the differences in the manure produced from different animals, a system to make methane from dairy cow manure is quite different from a digester for manure from swine. For dairy cows, a plug-flow digester system works well for collecting and breaking down manure and capturing the gas produced from this process. A completely mixed digester is better for swine manure (Goodrich, 2001).

Beyond their ability to manufacture biogas, digester designs based on use of thicker manures may offer the most benefits of the systems evaluated to date. Plug-flow digestion and its slurry cousin are economically sensitive to co-product use and other offsets from current manure management practices, but they are less expensive and technically easier to operate and maintain than a comparable complete-mix digester. Covered lagoon digesters appear to have economic merit for the large number of swine and dairy operations in the Southeast and West. Complete-mix digesters generally have higher capital costs and operating and maintenance requirements than slurry-based, plug-flow, and covered lagoon digesters. This will generally limit complete-mix digester applications to very large farms or centralized facilities, or to farms having waste streams with total solid concentrations too low for slurry and plug-flow digestion and to locations where the climate is too cold to economically justify covering an anaerobic lagoon (Lusk, 1998).

7.4.3 Operation and Performance

The successful operation of a properly designed anaerobic digester is dependent upon two variables, feed rate and temperature. All other operational issues are related to ancillary equipment maintenance. At face value, the performance data are not encouraging to a farmer considering whether to install an anaerobic digester as a waste treatment option. Overall, the chance for failure is approximately 50% in the United States (Lusk, 1998). Among the types of farm-based digesters actually built, the failure rates for complete-mix and plug-flow systems are staggering: 70% and 63%, respectively. For covered lagoon digesters, the failure rate is 22% (Lusk, 1998). However, a properly designed, constructed, and operated anaerobic digester is a low maintenance system that is very forgiving and not likely to create emergency situations that can be experienced with many alternative waste management systems (Saele). The failures of lagoons and the resulting waste spills have brought much of the recent critical attention to animal agriculture, and some have called for phasing out lagoons (Copeland, 1998).

Historically, one of the major problems with anaerobic digestion has been its unreliability. Because of the complex association of different types of bacteria, anaerobic digesters are prone to problems and have a higher risk of breakdown than other systems. The process is also more difficult to control (Cord-Ruwisch, 2001).

A review of anaerobic digestion project case studies revealed that the most common reasons for system failures include poor design and installation and poor equipment specification. Poor equipment and materials selection are also common reasons for failure. Other reasons that explain the failure of some anaerobic digestion projects include: insufficient gas production due to build-up from straw and foam, an inability to heat the digester to the desired level, insufficient insulation and agitation, grit deposition, engine corrosion, inadequate screening and sedimentation process, engine overheating, valve and pump problems, and maintenance costs (Lusk, 1998).

The improved reliability of newer systems and increased understanding of the biological systems that operate in an anaerobic digester suggest that the reliability of systems will continue to improve as long as lessons of past system failures are heeded (Lusk, 1998).

In spite of the chances of failure, survey farmers who have installed and continue to operate digesters are generally satisfied with their investment decisions. Some chose to install digesters for non-economic reasons, primarily to control odor or contain excess nutrient runoff. Farmers have found that the returns provided from electricity and co-product sales from the digester, however limited, are preferred to the sunk-cost of conventional disposal that provides zero return on investment. Moreover, without the environmental benefits provided by anaerobic digestion technology, some might have been forced out of livestock production (Lusk, 1998).

The anaerobic digestion process must be evaluated and implemented at each site. As a result, few meaningful generalizations may be made. Factors required for successful project implementation include: an adequate match of digester type to the farm's manure management program, competent design and installation, which simplify digester operation and maintenance, maximization of co-product use to enhance economic performance, and overall, an accommodating farm management and its willingness to incorporate the uncertainties of a new technology (Lusk, 1998).

7.4.4 Fuel Gas Production

Anaerobic digestion is the only waste management strategy available that provides the option to recover methane for energy production (McNeil Technologies, 2000). According to the USEPA AGSTAR Industry Directory for On-Farm Biogas Recovery systems, there are currently 89 agricultural methane recovery sites operating in the United States. A majority of the units are situated in the eastern region of the country. The digester technologies used to collect biogas from swine facilities include covered anaerobic lagoons, complete mix digesters, plug flow reactors, induced blanket reactors, and sequencing batch reactors. Although a sequencing batch reactor has been used for anaerobic digestion at one swine facility in the United States, this technology is considered to be experimental (McNeil Technologies, 2000).

Daily biogas production at installed farm-based anaerobic digesters in the United States varies from 24,000 to 75,000 cubic feet, or an energy equivalent of 13 to 42 million British thermal units (assuming 55 percent methane content for biogas). Approximately 35 percent of the volatile solids from dairy manure and 60 percent from swine or beef manure may be converted to biogas and removed from the manure liquid (U.S. EPA). The induced blanket reactor has achieved 80 % reduction of volatile solids.

Covered lagoon digesters and complete mix digesters differ in their methane production characteristics, and energy conversion systems that rely on methane from anaerobic digesters should be chosen according to the end-use objective for the system. Complete mix digesters may produce heat and electricity at a constant rate throughout the year because heat recovery may be used to heat the digesters in the winter. Covered lagoon digesters may consistently produce biogas only in months when the temperature exceeds 39 °F (Figure 7.6). Reactors may be successful in the northern United States if careful attention is paid to heat management. The facilities that are located in the southern portion of the country are usually warm enough for cost-effective energy recovery from covered lagoon digesters. Complete mix digesters may be used in cold or warm climates. If odor control is the only objective, either covered lagoon or complete mix digesters may be used, but odor control will be less effective in the winter for covered lagoon digesters in the south (McNeil Technologies, 2000).

Photo courtesy of USDA NRCS.

Figure 7.6. Covered manure tank generating methane in Iowa.

A review of recent dairy waste anaerobic digestion studies has established that most engineers anticipate a 50 percent conversion of volatile solids to gas. The planned Three-Mile Farm (Oregon) dairy waste thermophilic anaerobic digestion facility is expected to achieve a 50 percent volatile solids conversion to gas. The C. Bar M. (Idaho) plug flow anaerobic digester facility anticipated a 50 percent conversion of dairy waste volatile solids to gas. The recently completed Myrtle Point (Oregon) feasibility study utilizing the *gravity separation contact process* anticipated a 50 percent conversion of dairy waste volatile solids to gas. Relatively high loading rates were anticipated in each case. The organic loading rates varied between 5.6 and 6.4 $kg/m^3/d$ (Burke, 2001).

7.5 Technologies Requiring Significant Additional Research Before Implementation-Aerobic Digestion-Wetlands-Land Reclamation

7.5.1 Aerobic Digestion

The use of aerobic digestion to treat livestock wastes was born out of a need to reduce the pollution of both surface and ground water supplies, which had been caused by the spreading of manures, and the unavailability of land during much of the year for immediate spreading of animal wastes. For these reasons, farmers began to look for a low-cost, manure storage method that would not give rise to intolerable odors and insect breeding (U.S. EPA, 1972).

One of the simplest methods of low odor waste treatment is the aerobic biological treatment process. Aerobic treatment for the removal of biodegradable organic matter from liquid wastes is an odorless process and consists of two phases operating simultaneously. One phase is biological oxidation that has by-products such as carbon dioxide and water. The second phase utilizes the energy from the oxidation phase for synthesis of new cells (U.S. EPA, 1972). The degree of oxidation depends on the amount of oxygen provided, the reaction time allowed in the treatment process, and temperature. The relatively strong oxidizing environment leads to a more extensive breakdown of organic compounds, with water, carbon dioxide, nitrates, sulfates, and other simple molecules being the products (Bicudo, 2001). With conventional aerobic digestion, substantial reductions in total and volatile solids, biochemical and chemical oxygen demand, and organic N may be realized.

An aeration basin typically is used for the aerobic digestion of municipal and industrial wastewater biosolids. In contrast, several reactor types, including oxidation ditches and mechanically aerated lagoons, as well as aeration basins, have been used for the aerobic digestion of animal manures. Under commercial conditions, the oxidation ditch has been the most commonly used because it may be located in the animal housing unit under cages for laying hens or under slatted floors for swine (U.S. EPA, 2001).

7.5.1.1 Types of Aerobic Digestion Technologies

7.5.1.1.1 Oxidation Ponds

The oxidation pond (naturally aerated lagoon) is a shallow pond that uses a natural system of evaporation as a means of effluent reduction. In an aerobic lagoon or oxidation pond, there must be an abundance of dissolved oxygen available in the water for the aerobic bacterial and other organisms to interact in the biochemical process that decomposes or breaks down the organic materials in the liquid waste. Normally, aerobic lagoons range from 3 to 5 feet deep. If oxidation ponds are properly constructed and hold the wastes for a sufficient time, a good destruction of coliform organisms and a satisfactory reduction of BOD_5 occur. The effluent is usually high in dissolved oxygen (U.S. EPA, 1972). The main advantages of aerated lagoons are that aerobic digestion tends to be more complete and it produces fewer odors than anaerobic digestion (McNeil Technologies, 2000).

Because of the large surface area required, oxidation ponds have not found favor with livestock producers. Vast amounts of land are required – as much as 25 times more surface area and 10 times more volume than an anaerobic lagoon 10 feet deep. Thus, naturally aerobic lagoons are impractical for primary oxidation and are generally not recommended for treatment of livestock production wastes (Barker, 1996). Their use has been essentially limited to receiving effluent from anaerobic lagoons and other treatment units.

7.5.1.1.2 Mechanically Aerated Lagoons

A mechanically aerated lagoon is similar to a stabilization pond except that it is equipped with one or more electrically powered aerators that treat effluent by mixing it with air (Water for the World). Mechanically aerated lagoons combine the odor control advantages of aerobic digestion with relatively small surface requirements. Aerators are used mainly to control odors in sensitive areas and for nitrogen removal at limited land disposal sites (Barker, 1996). A major disadvantage of mechanically aerated lagoons is the expense of continually operating electrically powered aerators. Larger anaerobic lagoons may provide similar performance with less expense (Barker, 1996).

7.5.1.2 Application

Conventional aerobic digestion is a process used frequently at small municipal and industrial wastewater treatment plants for biosolids stabilization. Conventional aerobic digestion is an option for all swine and poultry operations where manure is handled as a liquid or slurry. With proper process design and operation, a 75 to 85 % reduction in BOD_5 appears achievable, with a concurrent 45 to 55 % reduction in

COD, and a 20 to 40 % reduction in total solids. In addition, a 70 to 80 % reduction of the N in both poultry and swine wastes via nitrification-denitrification also appears possible. Total P is not reduced, but the soluble fraction may increase (U.S. EPA, 2001).

Unlike anaerobic digestion, aerobic digestion has not been adapted to any significant degree by the poultry, dairy, or swine industries, although a number of research and demonstration scale studies were conducted in the late 1960s and early 1970s. Problems related to process and facilities design, together with the significant increase in electricity costs in the early to mid-1970s, led to a loss of interest in this animal waste treatment alternative. It is possible that no aerobic digestion systems for animal wastes are currently in operation in the poultry and swine industries.

7.5.2 Wetlands

7.5.2.1 Constructed Wetlands

Constructed wetlands (or treatment wetlands**)** are man-made, shallow ponds or channels that have been planted with emergent aquatic plants, and are designed, built and operated specifically for wastewater treatment. They rely upon natural microbial, biological, physical, and chemical processes to treat wastewater. To allow optimum process control, water control structures such as gates, valves and dikes have been engineered to control the flow direction, hydraulic retention time, and water level. They are typically constructed with uniform depths and regular shapes near the source of the wastewater and often in upland areas where no wetlands have historically existed. Constructed wetlands are regulated as wastewater treatment facilities and may not be used for compensatory mitigation (USEPA, 2000b).

7.5.2.2 Restored Wetlands

Created or restored wetlands are designed, built (or restored), and operated primarily for wildlife habitat and should not be confused with constructed wetlands. In an effort to mimic natural wetlands, habitat wetlands often have a combination of features such as varying water depths, open water and dense vegetation zones, vegetation types ranging from submerged aquatic plants to shrubs and trees, nesting islands, and irregular shorelines. They are frequently built in or near places that have historically had wetlands and are often built as compensatory mitigation. Created and restored wetlands are generally inappropriate for CAFO applications and are not discussed further.

7.5.2.3 Enhancement Wetlands

Enhancement wetlands are constructed wetlands providing polishing (advanced or tertiary treatment) of wastewater that has been extensively pre-treated, usually to secondary treatment standards. They are often designed, built, and operated for both wastewater treatment and other functions, such as wildlife habitat, outdoor classrooms, or recreational areas. While there may be applications for enhancement wetlands as a tertiary treatment process in certain circumstances, they are generally inappropriate for CAFO applications and are not discussed further.

7.5.2.4 Free Water Surface (FWS) Wetlands

Constructed wetlands have been classified in the literature and by practitioners into two types. Free water surface (FWS) wetlands, also known as surface flow (SF) wetlands, resemble natural wetlands in appearance because they contain aquatic plants that are rooted in a soil layer on the bottom of the wetland, and water flows through the leaves and stems of plants (Figure 7.7).

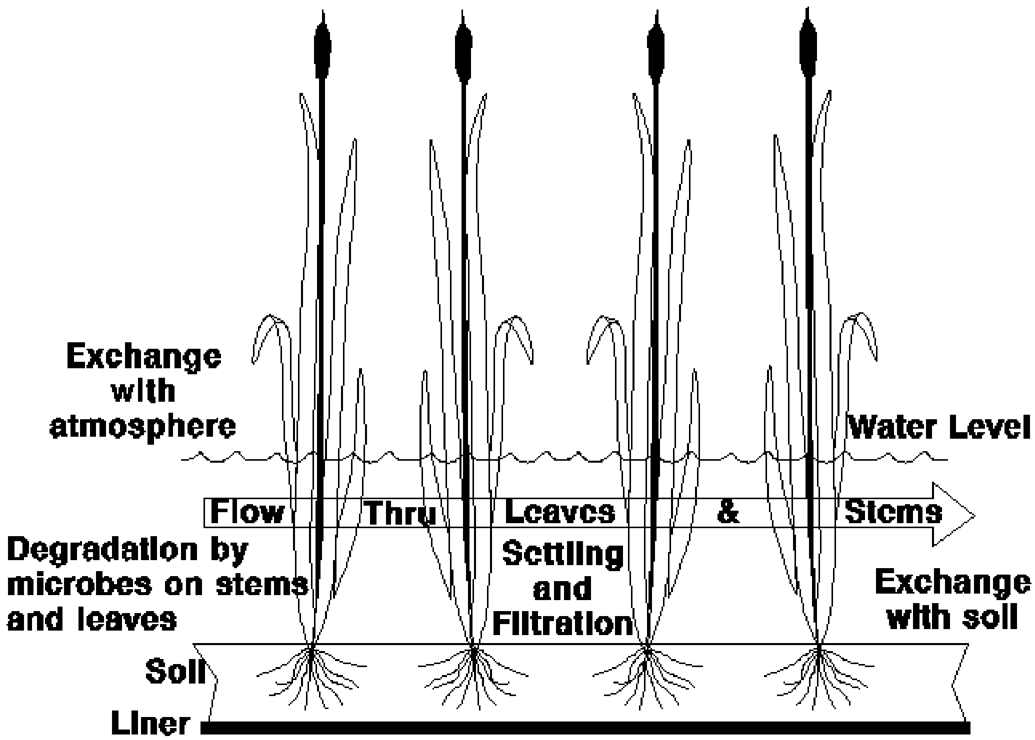

Figure 7.7. Free Water Surface (FWS) Wetland.

7.5.2.5 Vegetated Submerged Bed (VSB) Wetlands

Vegetated submerged bed (VSB) systems, also known as subsurface flow (SSF) wetlands, do not resemble natural wetlands because they have no standing water (Figure 7.8). They contain beds of media such as crushed rock, small stones, gravel, sand, or soil that has been planted with aquatic plants. When properly designed and operated, wastewater stays beneath the surface of the media, flows in contact with the roots and rhizomes of the plants, and is not visible or available to wildlife.

7.5.2.6 Reciprocating (ReCip) wetlands and vertical-flow (VF) wetlands

Reciprocating (ReCip) wetlands and vertical-flow (VF) wetlands are modifications of the VSB process. ReCip wetlands reciprocate flow back and forth between two VSBs in parallel in a way that allows the VSBs to alternate between saturated (anaerobic) and unsaturated (aerobic) conditions (Behrends, et al., 1996). VF wetlands are similar in design and operation to typical vertical flow, intermittent or recirculating sand or gravel filters, which have been planted with aquatic plants.

7.5.3 Treatment Mechanisms

The primary pollutant removal mechanisms for BOD_5 and solids (TSS) are physical removal and biodegradation. Physical mechanisms include impingement on plant or media surfaces, entrapment in plant parts or media, and sedimentation. All of these mechanisms are enhanced by the tortuous flow paths and quiescent hydraulic conditions found in wetlands. Once materials are removed from the water column by physical mechanisms, biodegradation occurs. Obligate and facultative anaerobic conditions predominate in VSBs and FWS wetlands, while the operating characteristics of ReCip and VF wetlands promote alternating anaerobic and aerobic conditions.

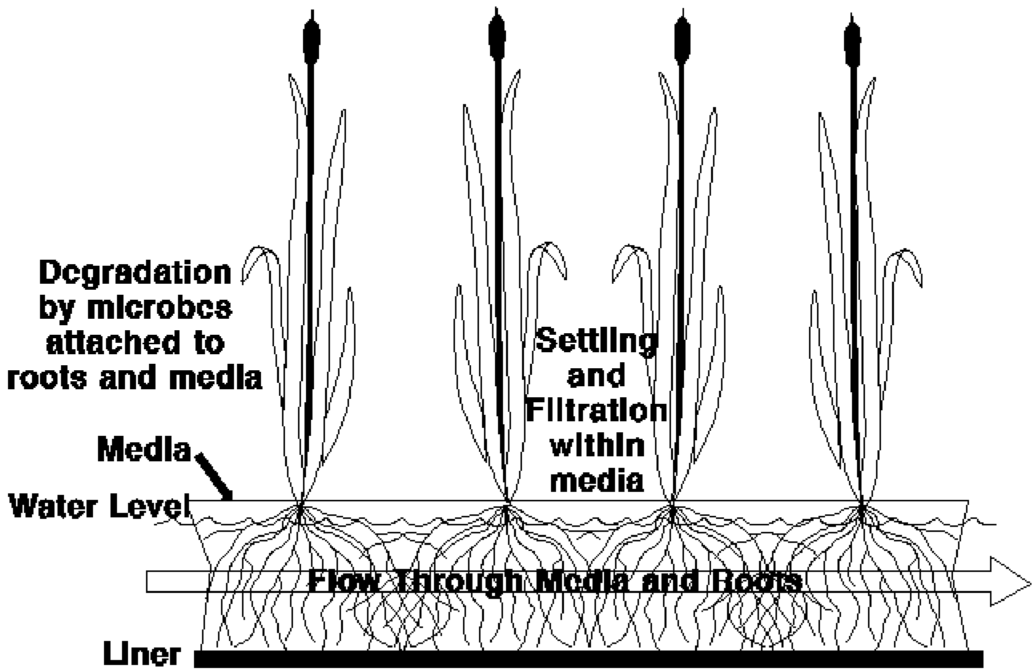

Figure 7.8. Vegetated Submerged Bed (VSB) Wetland.

For CAFO wastewaters (high BOD_5 and ammonia concentrations) in VSBs and FWS wetlands (shallow depths and large surface areas), ammonia volatilization may be a significant removal mechanism for nitrogen, especially in warmer climates. Wastewater lagoon studies indicate that nitrogen losses up to 95% may occur under ideal conditions, with ammonia volatilization being the dominant mechanism (Reed, et al., 1995). However, research is needed to verify this mechanism in constructed wetlands. Microbial nitrification/denitrification as a nitrogen removal mechanism in VSBs and FWS wetlands is less likely, because of the predominance of anaerobic conditions. Nitrification of ammonia is unlikely to occur in VSBs and will occur in the FWS wetlands only if adequate open water zones are incorporated into the design (USEPA, 2000a).

Phosphorus removal in all types of constructed wetlands is primarily limited to adsorption to solids. The adsorbing solids may be material in the influent wastewater, which has been removed from the water column, plant detritus, or the soil or media in the wetland. All of these materials have a finite adsorption capacity, so phosphorus removal may occur for a time when a constructed wetland begins operation, but removal will decrease or stop as adsorption sites are filled. Long term phosphorus removal will be limited to phosphorus that adsorbs to new material entering the wetland that is buried before the phosphorus may be released back into the water column (Kadlec and Knight, 1996). Because new regulations will likely make phosphorus the limiting factor for land application of wastewater (USEPA, 2001), an additional unit process to remove phosphorus will be required.

7.5.4 Plant Functions

The role of aquatic plants in the treatment process is still not clearly understood but appears to be limited primarily to providing an attachment surface for microbes in FWS wetlands. While emergent aquatic plants may provide oxygen from the atmosphere to their roots, field experience has shown that the small amount of oxygen that may “leak” from plant roots is insignificant compared to the organic and nitrification oxygen demands of heavily polluted wastewater applied at practical loading rates.

Nutrient utilization by plants is less than 20% of influent values for heavily polluted wastewaters (Reed, et al,1995) even if the plants are routinely harvested. If plants are not harvested, plant utilization is largely negated when the plants die in the fall and winter. Unless plant material containing nutrients is buried in the sediments before the nutrients leach out as the plants decompose, the nutrients will return to the water column.

Submerged aquatic plants in open water areas of FWS wetlands may supply oxygen to the wastewater during daylight hours. While they have been used in wetlands treating municipal wastewater, research is needed to determine their ability to tolerate heavily polluted CAFO wastewater. Floating aquatic plant systems (e.g. duckweed, water hyacinths, and algae) have been used to treat a variety of wastewaters. However, these systems require constant removal of plants and handling of the harvested material. While the harvested material may be processed and used as feed or land applied, very few operations using floating plants have succeeded in the U.S.

Researchers have hypothesized other plant functions in treatment wetlands. Plant detritus may provide carbon for microbial reactions and enzymes exuded by plant roots may enhance degradation of some organic compounds. Certain plant species may have symbiotic relationships with beneficial microbes attached to their roots, and these relationships could be useful for treatment purposes if they can be defined. Not enough research has been conducted to validate any of these functions.

7.5.5 Risk Associated with Constructed Wetlands

The use of constructed wetlands as a treatment technology carries some degree of risk for several reasons. First, although there is no evidence of harm to wildlife using constructed wetlands, some regulators have expressed concern about constructing a system that will treat wastewater while it attracts wildlife. Unfortunately, there has not been any significant research conducted on the risks to wildlife using constructed wetlands. Although they are a distinctly different type of habitat, lagoon treatment systems have not shown evidence of harm to wildlife. The fact that lagoon systems have been in use for many years suggests that there may not be a serious risk for wetlands treating agricultural wastewater. Of course, if a wetland is going to treat wastewater with high concentrations of known toxic compounds, the designer will need to use a VSB system or incorporate features in an FWS wetland that restrict access to wildlife.

Second, although many texts and design guidelines have been published for constructed wetlands in the past 10 years (Kadlec and Knight, 1996; Payne Engineering and CH2M-Hill, 1997; Reed, et al., 1998; USDA, 1991; USDA, 1995; USEPA, 2000a), questions remain about their application, design, and performance. Constructed wetlands are complex systems in terms of biology, hydraulics, and water chemistry. There is a lack of quality data of sufficient detail, both temporally and spatially, on full-scale constructed wetlands, forcing modelers and designers to derive design parameters by aggregating performance data from a variety of wetlands, which leads to uncertainties about the validity of the parameters. The design process is still empirical, that is, based upon observational data rather than scientific theories. Due to the variability of many factors at constructed wetlands that have been observed by researchers (e.g., climatic effects, influent wastewater characteristics, design configurations, construction techniques, operating parameters, and maintenance practices), there will continue to be disagreement about some design and performance issues for some period of time.

Third, there are several common misconceptions about constructed wetlands. Some people think that VSBs and FWS wetlands are aerobic systems, or at least have many aerobic microsites. As noted in the previous discussion of plants, this is not true. Another myth is that constructed wetlands remove large amounts of nutrients. As discussed previously, although some nutrient removal does occur, it is not at the high levels reported in some early research.

Finally, as noted in a review of constructed wetlands for wastewater treatment by Cole (1998), constructed wetlands are not uniformly accepted by all state regulators or EPA regions. Some authorities encourage the use of constructed wetlands as a proven treatment technology. Others still consider them to be an emerging technology due in part to concerns about the issues discussed above. As with any new treatment technology, uniform acceptance of constructed wetlands will take some time.

7.5.6 Application and Performance of Constructed Wetlands for Agricultural Wastewaters

Although an operation in Iowa has used a constructed wetland since the 1930's, constructed wetlands have been more commonly used to treat agricultural wastewaters in the United States for about 10 years. The USDA-NRCS issued guidance on constructed wetlands for agricultural wastewater treatment in 1991 (USDA, 1991). The U.S. EPA's Gulf of Mexico Program funded a project to assess the use of constructed wetlands for CAFO wastewater in the late 1990's (CH2M-Hill, 1997; Payne Engineering and CH2M-Hill, 1997; Knight, et al., 2000). The study depended primarily on data from a subset of the North American Treatment Wetland Database, v 2.0 (NADB) (USEPA, 1999) and summarized the performance of wetland systems (Table 7.3).

Table 7.3. Performance Data Summarized for Gulf of Mexico Program (CH2M-Hill, 1997)

Parameter	Influent (mg/L)	Effluent (mg/L)	Reduction (%)
BOD_5	263	93	65
TSS	585	273	53
Ammonia	122	64	48
Total Nitrogen (TN)	254	148	42
Total Phosphorus (TP)	24	14	42

The entire NADB lists 135 wetland treatment systems at 69 sites that use constructed wetlands to treat agricultural wastewaters (Table 7.4).

Table 7.4. Agricultural Treatment Wetlands in the NADB

Animal Type	Wetland Type						Total Systems	Number of Sites
	Marsh			Open Water	Floating Plants	Other or Not Shown		
	FWS	VSB	Other					
Dairy	50	1		2	2	5	60	39
Swine	40		18				58	19
Cattle	5	2				2	9	8
Poultry	2			1		2	5	1
Aqua	3						3	2
Total	100	3	18	3	2	9	135	69

The wetlands are located in 18 states throughout the United States and in 5 Canadian provinces. A wide variety of plant species have been used, but cattails (*Typha*), grasses/reeds (e.g. *Phragmites*), and sedges/rushes (e.g. bulrush (*Scirpus*)) were the predominant plants in 48%, 28%, and 14% of the systems, respectively. Floating plants, such as duckweed (*Lemna*), were predominant in 4% of the systems. The wetlands range from experimental systems at research farms to full-scale systems, so their size and costs vary greatly (Table 7.5). Because of the wide variation, the size and cost listed cannot be used for design purposes.

Table 7.5. Range of Costs and Operating Parameters for NADB Agricultural Treatment Wetlands

Parameter	Number*	Minimum	Maximum
Design Flow†	39	75 gpd	27,000 gpd
Area	127	43 sqft	116 ac
Area (per AU‡)	45	5 sqft/AU	6900 sqft/AU
Cost (per Area)	22	$1645/acre	$640,000/acre
Cost (per Flow)	13	$0.73/gpd	$174/gpd
Cost (per AU)	18	$76/AU	$6400/AU

*Number of systems in the NADB with data (out of the total of 135 systems)
†Actual flows were usually less
‡Animal Units

General treatment performance for several common wastewater parameters, shown as the 95% confidence interval about the mean, calculated from the NADB, is shown in Table 7.6. Because these are overall average values from all of the systems, regardless of size, flow or type of wastewater, the values shown cannot be used for design purposes. However, the numbers do give a general impression of the capabilities of constructed wetlands for treating CAFO wastewater. While it is obvious that effluent from these systems cannot be discharged to surface waters, the reductions are substantial and yield higher quality water for land application.

Table 7.6. 95% Confidence Interval about the Mean for all NADB Agricultural Treatment Wetlands

Parameter	Influent	Effluent	Removal
BOD_5	246 - 352 mg/L	99 - 136 mg/L	34% - 44%
TSS	501 - 956 mg/L	360 - 676 mg/L	18% - 35%
Ammonia	141 - 174 mg/L	79 - 102 mg/L	23% - 31%
TP	24 - 29 mg/L	15 - 18 mg/L	15% - 31%
Dissolved Oxygen	2.1 - 2.7 mg/L	1.4 - 2.0 mg/L	
Fecal Coliform	2×10^5 - 4×10^5	2×10^4 - 5×10^4	0.8 - 1.0 log

Figure 7.9 shows a hog operation with a lagoon flowing into a constructed wetland. The treatment efficiency is reported to yield an effluent of higher quality than a nearby municipal wastewater treatment plant. Figure 7.10 shows a ground level view of the wetland with the owner making observations for his records.

Photo courtesy of USDA NRCS.

Figure 7.9. View of a hog operation with a lagoon flowing into constructed wetlands for treatment of wastewater.

Photo courtesy of USDA NRCS.

Figure 7.10. Ground level view of constructed wetland with the owner making observations for his records.

The USEPA currently has an agreement with the Tennessee Valley Authority to evaluate the use of its ReCip system at a swine operation in Alabama. The system treats wastewater from the anaerobic lagoon that receives the flush water from the swine buildings. The preliminary results from the first year of operation are shown in Table 7.7. As expected from a system with alternating aerobic and anaerobic conditions, the ReCip systems had good BOD_5 and ammonia removal. Also as expected for any wetland system, phosphorus removal decreased from an initial 90% removal efficiency (< 10 mg/L in the effluent) to 20% removal (40 mg/L in the effluent) during the one year of operation.

Table 7.7. Preliminary Averages from ReCip System Treating Swine Wastewater

Parameter	Anaerobic Lagoon	ReCip Effluent	Removal
BOD	557 mg/L	108 mg/L	73%
Ammonia	371 mg/L	50 mg/L	86%
TP	51 mg/L	29 mg/L	43%
Fecal Coliforms			2 $\log_{10}$ units

7.5.7 Processes to Significantly Reduce Pathogens (PSRP)

Manure should be treated to effectively eliminate pathogens and applied appropriately to minimize the possibility of pathogen survival and subsequent crop contamination (IFT, 2002). An indication of the level of concern that World Health Organization (WHO), U.S. EPA, and the State of California place on the issue of proper application of recyclable materials to land is shown in Table 7.8 which presents microbiological quality guidelines and standards for the application of wastewaters to land. A PSRP is a technology that is broadly defined as one that reduces both the pathogen load and vector attraction in the environment (U.S. EPA, 1989). Typically, the pathogen reduction is a minimum of one order of magnitude.

Many factors may induce pathogen reduction occurring with various treatments such as temperature, storage length, and continuous addition of manure. Presently, facultative lagoons and composting are mostly used to manage waste at CAFOs. Likely, some pathogen reduction occurs, but it is difficult to quantify the amount. The methods that may be used in an animal feeding operation to treat manure and reduce pathogens include: composting; aerobic digestion, high temperature; anaerobic digestion at different temperatures; combinations of aerobic and anaerobic digestion; and long term storage of manure before land application.

7.5.8 Recommendation

Implement control technologies for treatment of animal waste to reduce pathogen loads prior to land application or off-site transfer. Based on review of the peer-reviewed scientific literature, and using best professional judgment, it is recommended to take steps now to reduce potential exposures to pathogens via this route. Several technologies have demonstrated the capability to significantly reduce the risk of pathogen contamination from land application of animal waste. The technologies also reduce the viability of *Cryptosporidium* oocysts, which have been found to be difficult to treat by publicly owned treatment works. These technologies are listed below.

7.5.8.1 Composting

Using either the within-vessel, static aerated pile or windrow-composting methods, the temperature of the animal wastes/manure is raised to 40^oC (104^oF) or higher and remains at 40^oC (104^oF) or higher for five days. For 4 hours during the 5-day period, the temperature in the compost pile exceeds 55^oC (131^oF) (U.S. EPA, 1989).

Table 7.8. Microbiological Quality Guidelines & Standards For Application Of Wastes To Land

Agency	Reuse Conditions	Helminths - No./100ml	Fecal Coliforms, No./100 ml	*Salmonella spp.*, No./ 100 ml	Enteric Viruses, No./100 ml
WHO	Crops likely to be eaten raw	≤ 1/L	≤1,000/100 ml	NR	NR
WHO	Pasture, fodder & industrial crops	≤ 1/L	NR	NR	NR
Blumenthal et al.	Crops likely to be eaten raw	≤ 0.1/L	≤ 1,000/100 ml	NR	NR
Blumenthal et. al.	Spray irrigation of pasture, fodder and industrial crops	≤ 1/L	≤ 100,000/100 ml	NR	NR
USEPA	Unrestricted irrigation of municipal Class A sewage sludge	< 1 helminth ova/4g total solids (dry weight)	< 1,000/g total solids (dry weight)	< 3/4g total solids (dry weight)	< 1 PFU/4g total solids (dry weight)
USEPA	Application of municipal Class B sewage sludge	NR	< 2 x 10^6/g total solids (dry weight)	NR	NR
NC Admin Code	Land discharge of reclaimed domestic wastewater	NR	< 14/100 ml)	NR	NR
Calif. Code of Reg	Irrigation of food crops, high exposure landscapes	NR	< 2.2/100 ml[b]	NR	NR
Calif. Code of Reg.	Irrigation of dairy pastures, low-exposure landscapes	NR	< 23/100 ml[b]	NR	NR

(a) NR = No standard recommended
(b) Standard for fecal or total coliforms

7.5.8.2 Air Drying

Animal wastes/manure is dried on sand beds or on paved or unpaved basins. The animal wastes/manure dries for a minimum of three months. During 2 of the 3 months, the ambient average daily temperature is above 0^oC (32^oF).

7.5.8.3 Facultative lagoons / Storage

Animal waste/manure is treated or stored in a lagoon system at a temperature of ≤ 5°C for a period of at least six months or at a temperature of > 5°C for a period of at least four months. Since all wastes must be in a lagoon for the specified period, two lagoons will likely be needed such that while one is filling, the other may be aging. This avoids short-circuiting.

7.5.8.4 Anaerobic Digestion

Animal waste/manure is treated in the absence of air for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature must be between 15 days at 35^oC (95^oF) to 55^oC (131^oF) and 60 days at 20^oC (68^oF) (U.S. EPA, 1989).

7.5.8.5 Aerobic Digestion

Animal waste/manure is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time (i.e., solids retention time) at a specific temperature. Values for the mean cell residence time and temperature must be between 40 days at 20°C (68°F) and 60 days at 15°C (59°F) (U.S. EPA, 1989).

7.5.8.6 Lime Stabilization

Sufficient lime is added to the animal waste/manure to raise its pH to 12 for ≥ two hours of contact. *****More detailed information on Technologies 1, 2, 4, 5, and 6 in *Environmental Regulations and Technology: Control of Pathogens and Vector Attraction in Sewage Sludge (EPA/625/R-92/013 – 1999 Edition.)*

Table 7.9 shows technologies for potential use at CAFOs and their expected effect on pathogen levels (USEPA, 2001).

Table 7.9. Effects of waste treatment and management systems on pathogen reductions.[1]

Treatment Process	Maximum Reduction (%)[2]	Animal Waste	Comments
Liquid Systems			
Anaerobic lagoons	99.0% per cell	swine, dairy, beef, layers	residence time of months
Aerated lagoons	99.0% per cell	swine, dairy, beef	residence time of months
Anaerobic thermophilic digesters	99.9%	swine, dairy, beef	Temperature- dependent
Anaerobic mesophilic digesters	99.0%	swine, dairy, beef	
Constructed wetlands	99.0% per cell	swine, dairy, beef	Do not work well with high solids content, temperature-dependent
Overland flow	50.0%	swine, dairy, beef	Temperature-dependent
Solids Separation			
Aerobic (liquid fraction)	99.0%	swine, dairy, beef	
Chemical (liquid fraction)	99.0%	swine, dairy, beef	Time-dependent
Alkaline treatment (liquid or dry)	99.9%	most	Time-dependent
Thermal Process			
55-60° C	99.9%	most	Time- and temperature - dependent
> 60° C	99.9%	most	Time- and temperature-dependent
Composting	99.9%	most	Time- and temperature-dependent, need mixing for aeration

[1]Summary from USDA/EPA "Workshop on Emerging Infectious Disease Agents and Issues Associated with Animal Manures, Biosolids, and Other Similar Byproducts" June 4-6, 2001 Cincinnati, OH. (Reference in bibliography section)
[2]Maximum pathogen reductions converted from $\log_{10}$ reductions (1 $\log_{10}$ reduction = 90.0%, 2 $\log_{10}$ reduction = 99.0%, 3 $\log_{10}$ reduction = 99.9%).

Most technologies currently or likely to be used by CAFOs reduce pathogen levels up to 99%. Several factors may impair the pathogen reduction obtained with these technologies. Most of these technologies are time-dependent (some requiring months of residence time) and pathogen reduction may be lower with reduced residence time. Some of these technologies operate under conditions of continuous addition of manure, which may impede pathogen reduction. Some of the technologies like constructed wetlands and composting operate optimally under specific solids level ranges (percentage) and could have poor pathogen reductions outside those optimums. Several of these technologies (anaerobic thermophilic digesters, constructed wetlands, and thermal processes) operate optimally under specific temperature ranges and could have impaired pathogen reductions outside those optimums.

7.6 Land reclamation

7.6.1 Non-Farm Land Applications

In large parts of the United States areas exist where untreated or semi-treated manures may be land-applied with little risk of pathogens reaching human receptors directly. These areas will allow aerobic degradation and provide a use for carbon and nitrogen in the materials. The needed research builds on the information learned from farm applications of feedlot waste, and extends it to new markets for the material. The main limitations to current off-site use of these materials are lack of information about the effects and economics of transportation.

There are two categories of non-farm land applications of CAFO wastes: on-site and off-site. On-site application could include CAFO controlled forest plots and wetlands, or perhaps a combination of trees, cropland, and wetland. Feed lot wastes could possibly be safely used on off-site applications, various land reclamation projects, forest crops, and on vegetation in uninhabited areas such as along highways.

Hard rock and coal mines have left sterile scars across thousands of square miles of landscapes in this country's mining regions, frequently covering topsoil layers with infertile subsoil, rock, and mine tailings. These are unsightly, have no habitat value, and often acidify rainwater causing downstream damage. Restoring these sites requires carefully reconstructing the conditions for pedogenesis, or soil creation. Organic material must be incorporated to establish vegetation, and annual or more frequent applications may aid in ensuring successful establishment of the conditions for sustainable vegetation. Similarly, restoration of coal mine sites may benefit from application of lime and organic material in the form of animal waste. Heavily eroded lands may also benefit from application of manure combined with dredge spoil as a step towards recreation of the soil surface.

7.6.2 Phytoremediation Projects, Sediment Recycling, and Landfill Covers

Small sites, ranging in the tens of acres, exist across the United States in locations that could potentially accommodate applications of CAFO materials several times per year. These sites are typically secure from casual human intrusion, and the plants grown on them are not consumed by people nor by livestock. Generally these sites pay for fertilizer and organic material, especially during initial installation, which could offset some transportation costs.

7.6.3 Riparian Corridors

Riparian corridors are stream bank and riverside strips of trees and other vegetation that separate agricultural fields from surface water and protect that water by filtering, degrading, and using excess fertilizer, herbicide, and pesticide. This run-off prevention system may be extremely effective both at improving stream cleanliness and at providing enhanced habitat for both terrestrial and aquatic species. Thousands of miles of riparian corridors have been planted and are continuing to be planted around the Chesapeake Bay and along the Mississippi watershed.

7.6.4 Forest Products: Short Rotation Wood Crops- Pulp & Paper, Lumber, Fuel

The wood products industry plants tens of thousands of acres of fast growing hybrid trees each year. These trees thrive on high nutrient levels. Regular applications of feedlot waste might be an ideal use if the transportation and safety considerations may be satisfactorily explored. Forest application of treated sewage sludge has been researched, and that work might be applicable to some extent.

7.6.5 Highways: Roadsides and Medians

The thousands of miles of grassy medians and roadsides present an opportunity for beneficial disposal of CAFO materials. Regular, thin applications of liquid or solid material could provide a safe area for aerobic degradation, distant from human contact, on plants not intended for livestock consumption.

Each of these areas has needs and concerns that should be researched before application. There should be an estimate of how many acres or square miles are available of each type of terrain in various geographic regions. Different regions have different usage opportunities; for example, Appalachia and the Rocky Mountains need organic material for hard rock mine reclamation, while the Great Lakes area have dredged sediments that need organic materials to encourage contaminant degradation and plant growth in order to turn dredged material into soil suitable for beneficial reuse.

Finally the loading rate limitation for each terrain and application needs to be determined. The quantity of waste that may be safely applied to a particular project depends on the form of the waste (solid or liquid), the nutrient and chemical load of the material, and the capacity of the application to hold and utilize the material. That capacity is, in turn, based on equipment limitations, nutrient use capacity of the particular vegetation, seasonal access to sites, and climate considerations. Each use would require research and experimentation to determine the type of equipment that would be needed for application in the target terrain.

A protocol that outlines how to match resources (waste sources) with utilizers within an economical travel distance would be extremely useful. Such a guide would help local feedlot farmers, foresters, ecological restorers and others answer those questions that prevent the synergies that allow use of this material as a resource.